20 Gb/s Electroabsorption Modulator Drivers based on 0.2 µm GaAs PHEMT

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Abstract

Electroabsorption modulator drivers using 0.2 µm gate length Pseudomorphic High Electron Mobility Transistors (PHEMT) for operation up to 20 Gb/s are presented. Both differential-pair based amplifiers and distributed amplifiers have been implemented and compared in terms of performances, power consumption, design, adaptability and adequation to the specific function to realize. It is shown that, in any case, an adaptation of the classical structure is necessary to get simultaneously the expected bit rate (20 Gb/s), drive voltage swing (2 Vp-p), and voltage gain (at least 10 dB).

Introduction

Large-signal and very large-bandwidth amplifier-modules tend to receive much interest as the bit rate of optical communication systems is increasing to 10 Gb/s and beyond [1,2,3]. This is especially the case of driver circuits for transmitters : the designer has to manage a compromise between bit rate, increasing rapidly, and swing-voltage needed for driving electrooptic modulators (about 6 to 10 Vp-p for a LiNbO3 modulator and 1.5 to 2 Vp-p for an electro-absorption s.c. modulator). Moreover, for electroabsorption modulators the swing-voltage and the bit rate tend to increase together because of the compromise between extinction ratio and bandwidth [4]. The classical approach for laser or modulator drivers is the differential-pair based circuit [1,2]. One of the major advantages of differential architectures is the small variation of the bias current during the signal switching, leading to high stability and less decoupling problems. However, the bandwidth varies as the inverse of the size of the transistors, and drivers are limited by the transistor gain-bandwidth product. In this paper, we propose two original solutions for overcoming this problem. The first consists in the modification of the differential amplifier by adding an appropriate high-speed output stage for reshaping the signal degraded by amplification. The second solution consists in the extension of the gain-bandwidth product by distributed amplification, the major drawbacks of which are the large semiconductor area it takes, and the very limited choice of architectures and functions. In our case, a modification of the classical distributed architecture has been necessary to achieve the appropriate voltage gain. For all the presented circuits, a state-of-the-art 0.2 µm gate length GaAs PHEMT technology from Philips Microwave Limeil has been used. Transition frequency (Ft) of 55 GHz, saturation current (Idss) of 210 mA/mm and threshold voltage (Vt) of -0.9V are the main characteristics of this technology.

Principle of operation

Due to its low chirp, external optical modulator is a good candidate for high-speed and long-haul optical fiber transmission systems [5]. The electroabsorption-type semiconductor modulators using the change of band-gap energy due to an applied electric field are very attractive, because they can achieve high-speed modulation under a relatively low driving voltage. For 20 Gb/s operation, electroabsorption modulators with 30 dB extinction ratio and driving voltage less than 2 Vp-p have been reported [6]. The possible connection schemes of the electroabsorption modulator with its driving circuit are summarized on figure 1.

The first option (fig.1a) is the classical 50 Ohms matching configuration. This allows total separation between the driver and the modulator; this means : modularity, weak influence of the driver heating on the electro-optic tranfer fonction and easier pigtailing of the modulator [7]. However, this solution leads to a low 25 Ω output load, which needs a strong driver output-stage, and induces bandwidth degradation. Also, it has to be noticed that half of the signal power is lost in the 50 Ω final matching impedance, which is not at all an optimum use of the driver ouput power. In addition, the limitation of the bandwidth caused by the external RC product, R being the equivalent load impedance (25 Ω) and C the value of the intrinsic capacitance of the modulator, cannot be exceeded. In consequence, it is obvious that the expected 2 Vp-p swing voltage and 20 Gb/s bit rate can hardly be achieved with classical 50 Ω differential pair or common source output stage. Distributed amplifier appears as the natural solution to maintain simultaneously 50 Ω matching and high cutoff frequency.

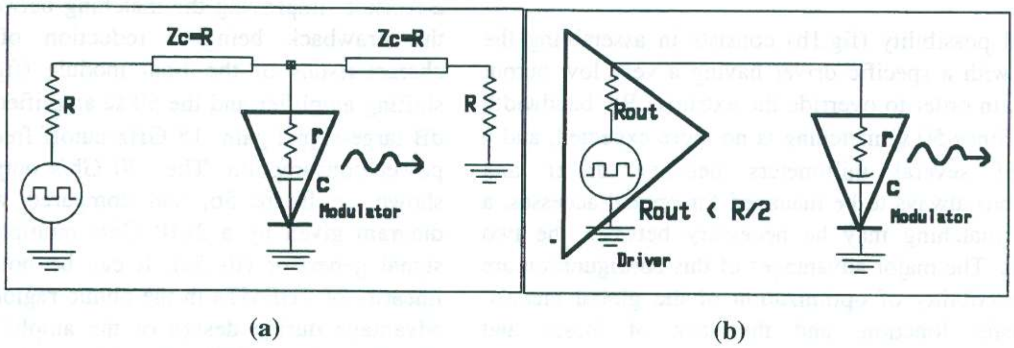

Figure 1 : Assembling options : (a) 50 Ω matching (b) low ouput impedance driving

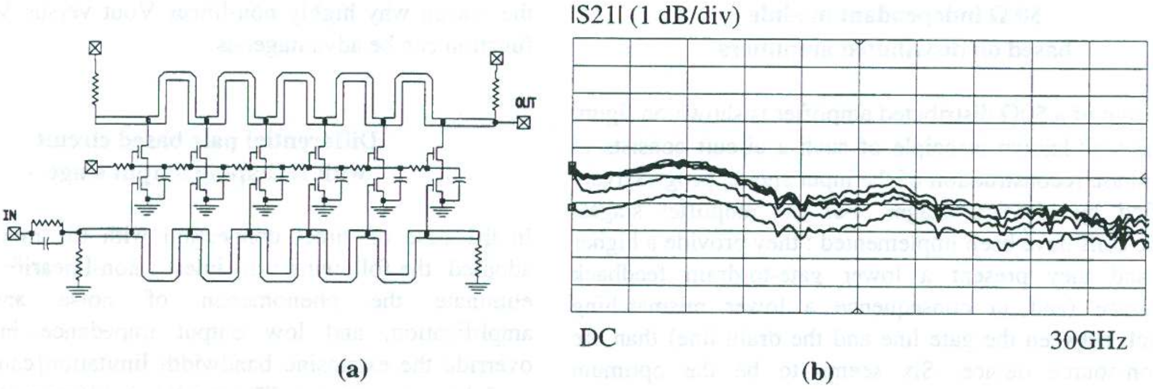

Figure 2 : 50 Ω cascode distributed amplifier (a) and its gain versus frequency curves measured on alumina substrate, for different operating points (b).

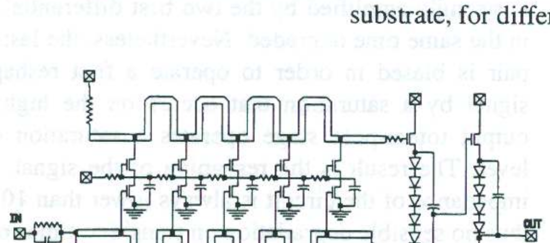

Figure 3 : Distributed amplifier with DC level shifting

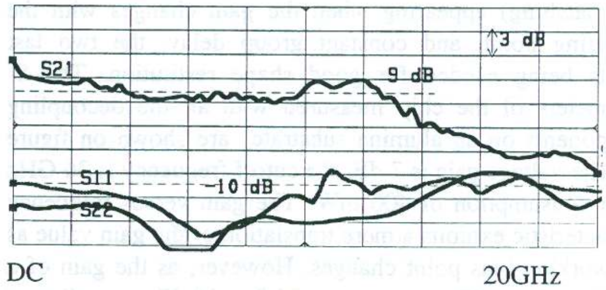

Figure 4 : Measured S parameters of the final module, cascading the two distributed circuits (fig. 2a & 3)

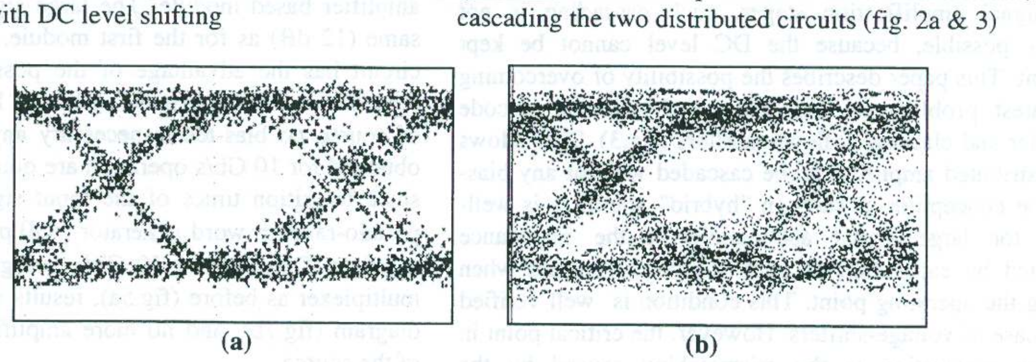

Figure 5 : (a) 2^7-1 eye diagram of the 2x10 Gb/s input generator (b) 2^7-1 20 Gb/s output eye diagram of the distributed circuits based module. The defect (jitter) on the high-to-low transition of the input signal is amplified.

The second possibility (fig.1b) consists in assembling the modulator with a specific driver having a very low output impedance, in order to override the extrinsic RC bandwidth limitation. Since 50 Ω matching is no more expected, and a distance of several millimeters between driver and modulator has always to be managed for optical accesses, a broadband matching may be necessary between the two components. The major advantages of this configuration are both the possibility of optimization of the global electro-optic transfer fonction, and the lack of losses and mismatching caused by connectors.

50 Ω independant module based on distributed amplifiers

The design of a 50Ω distributed amplifier is shown on figure 2a. The well-known principle of such a circuit consists in the in-phase reconstruction of the input signal, progressively amplified by identical stages. For the amplifier stages, cascode cells have been implemented : they provide a higher gain, and they present a lower gate-to-drain feedback capacitance (and in consequence a lower mismatching feedback between the gate line and the drain line) than the common-source device. Six seems to be the optimum number of stages, beyond which the gain-bandwidth product reduces. The key-points of the design of such distributed amplifiers devoted to large signal applications are : gain flatness, low S11 and S22 parameters, no important ripple (mismatching) appearing when the gain changes with the operating point, and constant group delay, the two last points being needed for good shape restitution. The S-parameters of the chip measured with all the decoupling components on an alumina substrate are shown on figure 2b. The voltage gain is 7 dB, the cutoff frequency is 36 GHz for a consumption of 400 mW. The gain versus frequency characteristic exhibits a mere translation of the gain value as the working bias point changes. However, as the gain of a distributed amplifier cannot exceed 8 or 10 dB, cascading of amplifiers is then necessary; but in the case of base-band large-signal amplification stages, such cascading is not directly possible, because the DC level cannot be kept constant. This paper describes the possibility of overcoming this latest problem by cascading a distributed cascode amplifier and classical follower-shifters (fig.3). This allows two distributed amplifiers to be cascaded without any bias-tee. The conception of such an "hybrid" amplifier is well-suited for large signal applications if the impedance presented by each stage is kept relatively constant when varying the operating point. This condition is well verified in the case of voltage-shifters. However, the critical point in such an association is the mismatching caused by the capacitive aspect of the input impedance of the follower stage loading the distributed stage. A solution is to introduce a resistor improving the matching between the two stages, the drawback being a reduction of bandwidth. The characteristics of the final module (fig.4), including the shifting amplifier and the 50 Ω amplifier cascaded, are : 12 dB large-signal gain, 15 GHz cutoff frequency, and 1.9 W power consumption. The 20 Gb/s output eye diagram is shown on figure 5b, and compared with the input eye diagram given by a 2x10 Gb/s multiplexer used as input signal generator (fig.5a). It can be noticed that the good linearity of PHEMTs in the ohmic region, (which is a great advantage during design of the amplifier), has the major drawback of amplifying the defects of the input signal (see fig.5). This phenomenon of accumulation of noise and distorsions is the major drawback of pure amplification, and the reason why highly non-linear Vout versus Vin transfer function can be advantageous.

Differential pair based circuit with reshaping output stage

In the case of direct connection with the modulator, we adopted the following principles : non-linearity in order to eliminate the phenomenon of noise and defects amplification, and low output impedance in order to override the extrinsinc bandwidth limitation caused by the modulator capacitance. The result is a differential-pair based circuit with a push-pull type output stage (fig.6). The signal is strongly amplified by the two first differential stages, and in the same time degraded. Nevertheless, the last differential pair is biased in order to operate a first reshaping of the signal by a saturation that occurs on the high level. The output totem-pole stage operates a saturation on the low level. The result is the reshaping of the signal. The output impedance of the circuit is always lower than 10 Ohms, and thus no sensible degradation on transition times occurs when the modulator is connected. Of course one drawback of this technique is the amount of power consumption, because of the high amplitude of signal needed for good reshaping. The power consumption of the circuit is about 3 W, and has to be compared with the 1.9 W consumption of the distributed-amplifier based module. The large signal gain is quite the same (12 dB) as for the first module, but the "totem-pole" circuit has the advantage of the possibility of direct and separate adjustement of the "0" and "1" voltage levels, and of course no bias-tee is necessary any longer. The results obtained for 10 Gb/s operation are quite interesting (fig.7a), since transition times of the input signal provided by the pseudo-random word generator (≈30 ps) have been reduced to 15 ps. Operation at 20 Gb/s, using the same 2x10 Gb/s multiplexer as before (fig.5a), results in a well opened eye-diagram (fig.7b), and no more amplification of the defects of the source.

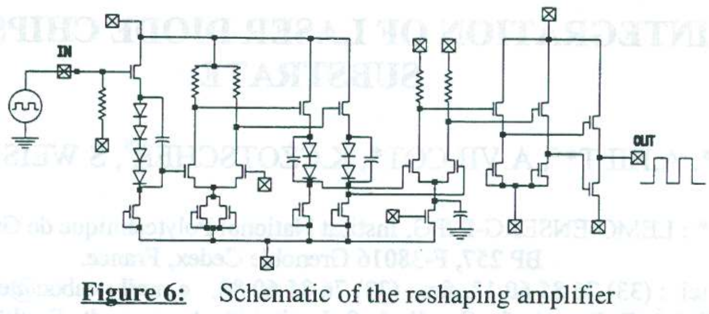

Figure 6: Schematic of the reshaping amplifier

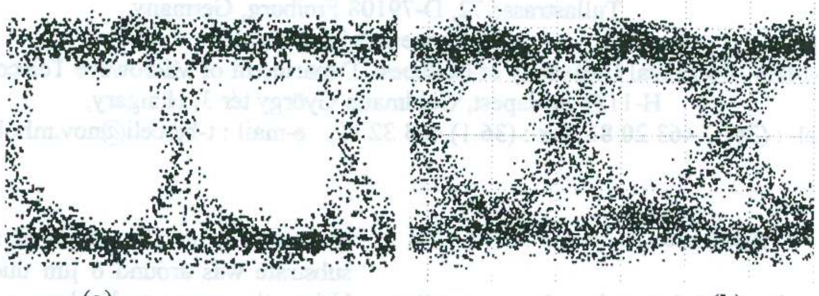

Figure 7 : 10 Gb/s (a) and 20 Gb/s (b) 2^7-1 electrical eye diagram measured with the circuit presented figure 6 mounted on alumina substrate with all the decoupling components and the modulator.

Conclusion

Two different 20 Gb/s electroabsorption modulator drivers using 0.2 µm gate length GaAs PHEMTs have been realized and compared. It is shown that in the case of a differential-pair based architecture, the non-linear large-signal transfer function offers the advantage of an isolation against noise and input signal imperfection. This can even be optimized in order to produce a reshaping of the signal. On the other hand, distributed amplifiers have the advantage of providing low consumption; but a modification of the classical schematic is then needed when cascading such amplifiers. The results obtained are at the world state-of-the-art level. The drivers presented here have been associated with EA modulators and are under optical experiments.

References

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